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Effect of global warming on rice culture and adaptive strategies

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ABSTRACT

The Fourth Assessment Report of Intergovernmental Panel on Climate Change in 2007 implied the increasing trend in global temperatures associated with anthropogenic greenhouse gases concentrations. In recent years, negative effect by high temperature to rice yield and grain appearance quality is recognized even in sub-tropical and temperate areas. High temperature induced sterility is most serious threat by high temperature on yield reduction. Occurrence of chalky grain is now crucial issue in Japan. Although high temperature during early ripening stages is a major trigger for chalky grain, other climatic conditions such as radiation, agronomic techniques and rice varieties are also responsible. This indicates the importance of integrated measure of variety and crop management to mitigate negative effect of high temperature.

Key words: rice, high temperature, grain quality

INTRODUCTION

The Fourth Assessment Report of Intergovernmental Panel on Climate Change (IPCC) in 2007 strongly implied that the increasing trend in global temperatures since the mid-20th century is the result of increase in anthropogenic greenhouse gases concentrations. High atmospheric CO_2 leads to the increase in biomass

production and yield through enhanced photosynthesis. On the other hand, it has been known that high temperature above optimum has negative effect on yield and grain quality in rice by inducing decline of grain setting, reduced grain weight, increased respiration, and also through aggravating biotic stress. Importantly, high temperature indirectly suppresses rice production by increasing water demand in water-limited area. Coping with these constraints derived from rising temperature will maximize the beneficial effect by CO_2 increases. Developing adaptive strategies to increasing temperature by understanding the response of rice to high temperature are crucial challenges in rice research. This paper reports on current knowledge on physiological response of rice to high temperature mainly based on experiences in Japan and discuss adaptive strategy.

YIELD AND GRAIN SETTING

Spikelet formation

The effect of temperature on yield appears through the changes in biomass production and harvest index. Generally, harvest index is more fluctuant as compared with biomass production due to higher sensitivity to temperature in spikelet formation, grain setting and grain filling. The study in western Japan (Suzuki 1980) showed that high temperature has positive effect on biomass production at early stages by enhancing tillering, leaf expansion and nutrient uptake. While, positive effect by higher temperature on biomass is less or becomes negative in later stages due to larger burden from increased maintenance respiration associated with excessive growth, faster senescence, and shortened growth period.

The factors causing reduction in harvest index by high temperature include decreased number of spikelet, sterility, and reduced single grain weight. Lowered spikelet formation efficiency, which is defined as spikelet number per unit biomass or unit N uptake at heading stage, is partly attributed to increased

proportion of unproductive tiller, lowered number of spikelet per panicle caused by excessive vegetative growth and reduced N uptake. Yield decline trend with decreasing biomass and spikelet number was observed in long-term experiment in the Philippines (Peng et al 2001). It appeared to be associated with increase in daily minimum temperature. Physiological mechanisms underlying specific effect of high night temperature on the spikelet formation remain unclear for further study.

High-temperature-induced sterility

Floret sterility induced by high temperature above 35 ^{o}C (Satake and Yoshida 1978) is most serious threat to reduce grain yield. High temperature-induced sterility has been reported in the tropics, and recently in China (Wang 2002). In the hot summer of 2007, increase in sterility rate was observed in farmers fields in central Japan (Hasegawa et al 2009). The most sensitive stage to high temperature-induced sterility is anthesis followed by young microspore stages (Satake and Yoshida 1978). High day temperature at anthesis time induces sterility by reducing the number of pollen grain shed on stigma. Morphologies of anther which affect theca dehiscence are proposed to be responsible for genotypic difference in sensitivity of pollen shedding, such as thickness of locule wall, length of dehiscence at basal part of theca (Matsui et al 2001, 2005). It was also proposed that the traits that flower early morning or night, which is found in cultivated rice species and wild relatives, may also be useful to escape from high day temperature (Nishiyama and Blanco 1980).

We need more information on critical temperature and stages under field conditions to assess the risks of sterility under global warming. Field observation in open field (Hasegawa et al 2009) implied that sterility rate with air temperature above 35 ^{o}C was considerably lower than that predicted from the results obtained in chamber experiment. Possible factor explaining these differences between

chamber experiments and field include temperature gaps between air and spikelet, physiological status of the plant grown in field and pot.

GRAIN FILLING AND QUALITY

Effect of temperature on grain quality

High temperatures during ripening stages lead to smaller grain size and deterioration of grain appearance quality such as chalky grain and fissured grains. Under high temperatures, increase in grain weight is accelerated in the early ripening stages while duration of ripening period becomes shorter, which results in smaller final grain size (Sato and Inaba 1976). In recent years, high temperature above 26-27 ^{o}C during early ripening stages increase the occurrence of chalky grain and fissured grain in Japan (Fig. 1)(Kondo et al. 2006, Nagata et al. 2004, Terashima et al. 2001). Chalky grains are composed of various types such as white-backed, milky white, white-belly, and white-based grain having different opaque endosperm portion. Milky white grain seriously degrades the market value. Not only high temperature, but also other climatic conditions such as low radiation, typhoon and plant factors such as high spikelet number are important factor to cause milky-white grain.

Gain chalkiness is suggested to be caused by disorder of starch accumulation processes based on the fact that opaque portions of chalky grain, amyloplast development is abnormal (Zakaria et al 2002). The causes of chalkiness and small grain are hypothesized to be source limitation and/or disorder of starch synthesis processes. There are two major sources of carbon for starch synthesis in the endosperm, newly photosynthesized carbon from leaf and accumulated non-structural carbon, mainly starch and sugars, in stem and leaf sheath.

Photosynthetic rate at single leaf level is relatively stable under short-term exposure to wide range of temperature, e.g. 24 - 36 ^{o}C (Vong and Murata 1977).

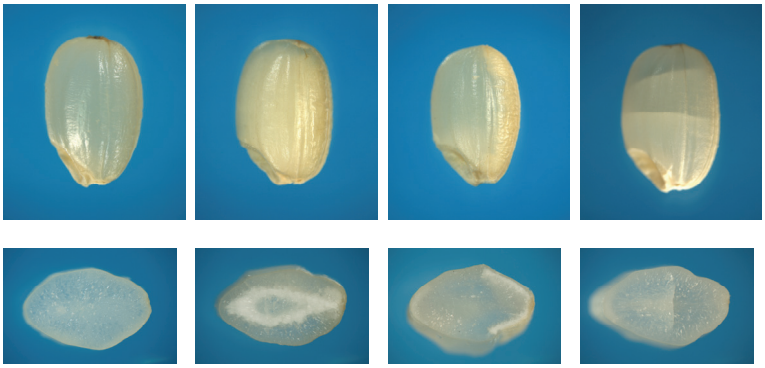


Fig. 1. Various types of grain appearance quality. From left: perfect grain, milky-white grain, white-backed grain, fissured grain. Photograph by N. Iwasawa.

The effect of high temperature on canopy photosynthesis under longer exposure to high temperature in field conditions is more complex since water and nutrient status of the plant are affected by temperature. The duration of active photosynthesis becomes shorter due to faster leaf senescence. During grain filling under higher temperature, decrease of non-structural carbon becomes faster, which indicate that carbon source for starch synthesis in endosperm depends more on reserved carbon in stem and leaf sheath to satisfy the increased carbon demand with accelerated grain filling. Further study is desired on the spatial and temporal substrate levels in endosperm as affected by temperature to clarify the involvement of limitation in substrate supply for starch synthesis.

The results in separate high temperature treatment on panicle and vegetative organs showed that treatment on panicle had more pronounced effect on final grain size and quality although vegetative organs were also sensitive to temperature to less extent (Sato and Inada 1973). It has been reported that activity and expression of some key enzymes involved in starch synthesis from ADP-glucose and conversion of sucrose to ADP-glucose are lowered under high temperature in cereal grains. In rice, high temperature depresses the expression of granule-bound starch synthase I, branching enzymes, and ADP-glucose

pyrophosphorylase while enhances expression of amylase (Yamakawa et al. 2007). Since the expression of genes and enzymic activity are affected by the substrate levels, the interaction of source and sink ability in response to high temperature should be further studied.

ADAPTIVE MEASURES

Cultivation methods

The agronomic countermeasures against high temperature damage include shifting cropping seasons, improving crop, soil, and nutrient management. Escaping from high temperature from anthesis and early ripening stage by moving transplanting date is the first major way in cropping system. The most sensitive period to high temperature is first 20 days after heading for chalky grains. Lowering expected temperature in this critical period by delaying of transplanting date has been successful to improve grain quality to some extent. Low N status magnifies the deterioration of grain quality, especially enhancing white-backed and white-base grains. Application rate of N has been decreasing since 1980s because of consumer's preference for low protein content in the grain. The low N application rate, in turn, induces the increased sensitivity to high temperature. Maintaining appropriate N status during ripening is important to maintain grain quality. Maintaining favorable soil conditions for root functions to ensure photosynthesis is important in soil management. Photosynthesis may be suppressed by high temperature due to reduced stomatal conductance, possibly related to the limitation of water uptake by root (Tsuno and Yamaguchi 1987). High soil temperature suppresses root growth (San-oh and Kondo 2006). Lowering soil temperature by cold water irrigation is effective to reduce fissured grain with the condition that water availability is not limited. The early drainage before harvest induces water stress that enhances deterioration of grain quality.

Varietal improvement in grain quality

Genotypic variations have been reported in sensitivities to high temperature in chalkiness and grain size. Genetic analyses for white-based and white-backed grains have been performed using japonica genotypes and several candidate QTLs were identified (Kobayashi et al. 2007, Tabata et al. 2007). Identification of the physiological functions of these QTLs is now under way. The genotypic differences in susceptibility to milky-white grains and grain size are less clear at present. Putative physiological and morphological traits related to the milky-white grain and grain size include stable sink ability under various temperature ranges, high source ability, low panicle temperature, and morphologies of the panicle and grain.

Future research

In physiological aspects, detailed understanding is required to clarify key carbon metabolisms which confer stable grain development under high temperature and low radiation. Genotypic improvement in adaptability to high temperature in spikelet formation, sterility and grain filling under are desired using wider germplasms. Limited information is available in genetic diversity in optimum temperature in grain filling and photosynthesis. Understanding the genetic factor and agronomic measure to control stomatal conductance would be useful because it determines canopy temperature and also affect water use. Increasing temperature is anticipated to have not only negative impact, but also positive aspects such as expanding crop growing spell. Development of crop production system which maximizes beneficial effect of global warming should be also considered.

REFERENCES

Hasegawa T, Yoshimoto M., Kuwagata T, Ishigooka Y, Kondo M, Ishimaru T. 2008. The impact of global warming on rice production. Lessons from spikelet sterility observed under the record hot summer of 2007. NIAES Annual Report 2008, 23-25. http://www.niaes.affrc.go.jp/annual/r2008/index.html.

Kobayashi AKobayashi A, Genliang B, Shenghai Y, Tomita K. (2007). Detection of quantitative trait loci for white back and basal-white kernels under high temperature stress in japonica rice varieties. *Breed. Sci.* 57: 107–116.

Kondo M, Morita S, Nagata K, Koyama Y, Ueno N, Hosoi J, Ishida Y, Yamakawa T, Nakayama Y, Yoshioka Y, Ohashi Y, Iwai M, Odaira Y, Nakatsu S, Katsuba Z, Hajima M, Mori Y, Kimura H, and Sakata M. 2006 Effects of air temperature during ripening and grain protein contents on grain chalkiness in rice. Jpn. J. Crop Sci.75 Suppl.2:14-15.

Kondo M, Kuwagata T, Ishigooka Y, Toritani H, Hasegawa T, Sasahara K, Ishimaru T, and Sanoh Y. 2007 Analysis on the effect of climatic conditions on the occurrence of milky white grain and white base grain using national statistical survey on rice. J. Crop Sci. 76 Suppl.1:210-211.

Matsui T, Kobayashi K, Kagata H, and Horie T. 2005 Correlation between viability of pollination and length of basal dehiscence of the theca in rice under a hot-and-humid condition. Plant Prod. Sci. 8:109-114.

Matsui T, Omasa K, Horie T. 2001 Comparison between anthers of two rice (Oryza sativa L.) cultivars with tolerance to high temperatures at flowering or susceptibility. Plant Prod. Sci. 4:36-40.

Nagata, K., Takita, T.,Yoshinaga, S., Terashima, K., Fukuda, A. 2004. Effect of air temperature during the early grain-filling stage on grain fissuring in rice. Japanese Journal of Crop Science, 73:336-342.

Nakagawa H, Horie T and Matsui T 2003 Effects of climate change on rice production and adaptive technologies. In “Rice Science: Innovations and Impact for Livelihood.” Mew, T.W., Brar, D.S., Peng, S., Dawe, D. & Hardy, B. eds., International Rice Research Institute, pp.635-658.

Nishiyama I and Blanco L 1980 Avoidance of high temperature sterility by flower opening in the early morning. JARQ. 14:116-117.

Peng S, Huang J, Sheehy JE, Laza RC, Visparas RM, Zhong X, Centeno GS, Khush GS, Cassman KG 2004. Rice yields decline with higher night temperature from global warming. Proc. Natl. Acad. Sci. USA 101:9971-9975

San-oh Y and Kondo M 2006 Effects of soil temperature on growth, grain quality and root function in rice. Jpn. J. Crop Sci. 75 suppl. 1:234-235.

Sato K and Inaba K.1973. High temperature injuries to ripening of the rice plant. 2. The ripening of rice grains when panicle and straw were separately treated under different temperature. Proc. Crop Sci. Soc Jpn. 42:214-219.

Sato K and Inaba K. 1976. High temperature injuries to ripening of the rice plant. 5. An early decline of the assimilate storing ability of rice grains under high temperature. Proc. Crop Sci. Soc Jpn. 45:156-161.

Satake T and Yoshida S 1978 High temperature-induced sterility in indica rices at flowering Jpn. J. Crop Sci. 47:6-17.

Suzuki M. 1980. Studies on distinctive patterns of dry matter production in the building process of grain yields in rice plants grown in the warm region in Japan. Bull. Kyushu Nat. Agri. Exp. Sta. 20:429-494.

Tabata M, Hirabayashi H, Takeuchi Y, Ando I, Iida Y, Ohsawa R 2007. Mapping of quantitative trait loci for the occurrence of white-back kernels associated with high temperatures during the ripening period of rice (*Oryza sativa* L.) Breed. Sci. 57: 47–52.

Terashima K, Sato Y, Sakai N, Watanabe T, Ogata T, Akita S (2001). Effect of high air temperature in summer of 1999 on ripening and grain quality of rice. *Jpn. J. Crop Sci.*70:449-458.

Tsuno Y and Yamaguchi T 1987 Relationship between respiratory rate of root and temperature modulated photosynthesis in rice plant and the factors concerning the respiratory rate of root. Jpn. J. Crop Sci. 56:536-546

Vong NQ and Murata Y 1977 Studies on the physiological charactereristics of C3 and C4 crop species. Jpn. J. Crop Sci. 46:45-52

Wang C, Yang J, Wa J, and Cai Q 2004 Influence of high and low temperature stress on fertility and yield of rice (*Oryza sativa* L.):Case study with Yangtze River rice cropping region in China. Abstract World Rice Research Conference 2004. p97.

Yamakawa, H., T. Hirose, et al. 2007. Comprehensive expression profiling of rice grain filling-related genes under high temperature using DNA microarray. Plant Physiol. 144: 258-277.

Zakaria S, Matsuda T, Tajima S, Nitta Y. 2002 Effect of high temperature at ripening stage on the reserve accumulation in seed in some rice cultivars. Plant Prod. Sci. 5:160-168.